Sleep and Performance Measures in Soldiers Undergoing Military Relevant Training

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ABSTRACT

Inadequate sleep is known to impair a variety of cognitive capacities, including attention, vigilance, concentration, memory encoding, and some aspects of higher order reasoning and judgment. The ability to unobtrusively measure fatigue and predict its effects on cognitive performance is vital to successful military operations. Wrist actigraphy is one such method, but its ability to accurately measure and predict performance in militarily relevant activities is not well validated. Healthy military volunteers ($N = 108$) were fitted with wrist actigraphs (Actiwatch; Minimitter Inc.) while undergoing one of six military education programs lasting between 4 to 6 weeks. Sixty-four Actiwatches were worn consistently and yielded valid data. Actigraphic sleep data were analyzed with Actiware 3.41 using automated scoring algorithms. Indices of sleep duration, latency, and quality were used to predict academic success in these courses. Averaging across all courses and volunteers, Soldiers obtained 5.8 hours of sleep per night ($SD = 0.5$). Sleep duration was typically reduced to 4.6 ($SD = 1.5$) hours the night preceding an exam. Regardless of course type or test content, academic performance was significantly predicted by total sleep time (48 hours before, $r = .60, p < .001$; 24 hours before, $r = .54, p < .001$), sleep latency (48 hours before, $r = -.46, p = .002$; 24 hours before, $r = -.46, p = .002$), number of immobile minutes (48 hours before, $r = .58, p < .001$; 24 hours before, $r = .52, p = .001$), and fragmentation index (48 hours before, $r = .29, p = .05$; 24 hours before, $r = .28, p = .05$), but not total activity level (48 hours before, $r = .06$, ns; 24 hours before, $r = .07$, ns). Regardless of course or exam content, academic performance was significantly related to the amount and quality of sleep obtained within the 48-hour period preceding the exams. Actigraphy appears to be a valid and unobtrusive method for predicting academic performance in military courses, although issues of participant compliance and detection of off-wrist periods need to be improved.

1. INTRODUCTION

The quantity of rest and sleep obtained by ground and air warfighters are primary factors that determine their levels of alertness and performance. Providing information regarding the performance potential/status of individual Soldiers and groups of Soldiers would enhance military leaders' abilities to select the most suitable Soldier(s) for a given task/mission in order to maximize mission effectiveness.

Around-the-clock military operations today are the norm rather than the exception (Miller, 2005); with night operations a significant component of combat and training missions (Comperatore et al., 1993). Soldiers are often required to work for long periods of time without rest. This lack of rest can degrade Soldiers' ability to perform their duties efficiently, correctly, and in some cases, safely (Caldwell and Caldwell, 1993). In addition, Lieberman et al. (2005) report that there is considerable anecdotal documentation that combat-like stress can have a deleterious impact on the ability of warfighters to process cognitive information and act quickly, effectively, and decisively on the battlefield.

2. BACKGROUND

Assessing performance under combat-like activity and stress is critical for military field studies. Activity monitors are one of the few devices that are capable of monitoring human activity and behavior in free-living humans in the field on a minute-by-minute basis. These minimally invasive monitors, principally worn on the wrist, have been used to produce graphical represent-tations of subject activity (actigraphy) and have been successfully employed in Army field studies to assess sleep and performance (Lieberman and Coffey, 2000). During one such study in which the efficacy of melatonin was tested, Comperatore et al. (1996) were able to document Soldier adaptation to new work schedules by correlating actigraphy and Soldiers' cognitive performance.

Researchers have demonstrated the ability of actigraphs to predict sleep versus wakefulness for many years (Kripke et al., 1981; Webster et al., 1982; Cole and Kripke, 1988; Sadeh et al., 1989). Caldwell and Caldwell (1993) cautioned that although wrist activity monitors (WAMs) are good instruments for estimating sleep time, they cannot be used to determine the quality of sleep. When compared with the electroencephalo-graph (EEG), their study showed that the WAM agreed 89 percent (%) of the time. Since EEGs are not practical

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for field studies, WAMs are considered and accepted by the scientific community as reasonable substitutes.

One such WAM is the Actiwatch®, produced by Mini Mitter, a Respironics Company, and was the data collection device used in this effort. According to the Actiwatch® Instructional Manual (2001), the Actiwatch® is a small, lightweight, limb-worn, device which utilizes an accelerometer to monitor the occurrence and degree of motion. The sensor integrates the degree and speed of motion and produces an electrical current that varies in proportional magnitude at a sampling rate of up to 32 Hz. It contains an omnidirectional sensor and is thus, sensitive to motion in all directions. Once collected, the data are wirelessly downloaded to a reader which is connected to a personal computer. Accompanying Actiwatch® software allows the manipulation, analysis, and presentation of the data. The standard Actiwatch® is a durable device which was used in Iraq under actual combat conditions. It has been designed with a water-resistant case for use at pressures up to 1 atmosphere.

Today's warfighters may be required to operate technically sophisticated modern weaponry under conditions of sleep deprivation, sleep inertia (the state of grogginess and disorientation commonly experienced on waking from sleep), and the "fog of war." All of these conditions have detrimental effects on human performance and cognition (Wertz et al. 2006; Lieberman et al., 2005; Belenky et al., 2003; LeDuc, 2000; Caldwell et al., 1999). Kruger (1989, summarized by Caldwell et al.), reviewed numerous studies on the effects of sustained work and sleep loss, and indicated that sleep deprivation: 1) increases mental lapses which have an impact on the speed and accuracy of responses; 2) reduces ability to acquire and recall information in complex tasks; 3) produces changes in brain activity associated with decreased alertness; and 4) slows cognitive ability in which task performance declines in conjunction with mood and motivation.

3. METHODS

The study protocol was approved in advance by the U.S. Army Aeromedical Research Laboratory (USAARL) Human Use Committee. The principal investigator (PI) provided detailed briefings to the Commanders explaining the purpose, procedures and risks of the study and the actions required of those personnel who might volunteer to participate. Upon receiving the Commanders' approvals, the PI provided each interested Soldier with a comprehensive briefing regarding the study's specifics. Following the presentation, each Soldier met with an ombudsman to clarify and explain any remaining concerns. Those who still

wished to participate provided written informed consent before participating.

3.1 Study population and description

The study population was composed of 108 military personnel of the age of majority undergoing military training at the Noncommissioned Officer (NCO) Academy and the Warrant Officer Candidate (WOC) School at Fort Rucker, AL. Two participants were withdrawn from the study for failing to complete NCO courses, leaving a total of 106 participants. The data collected was from a diverse military population (NCOs and warrant officer candidates; both men and women) and on a wide range of training and performance measures.

3.2 Measures

Soldier activity data (the predictor variable) was collected using the Actiwatch® activity monitoring system. The output data used in this study's analyses were:

1. Assumed sleep - reflects the amount of time between the point at which it appeared that the onset of the sleep period began and the time the wearer finally arose from sleep.
2. Actual wake time - reflects the number of minutes of time within the assumed sleep period that were spent awake (i.e., not scored as sleep).
3. Sleep efficiency - indicates the percent of time that the wearer was assumed to be "in bed" or attempting to sleep that was actually spent asleep.
4. Number of sleep bouts - reflects the number of independent bouts of sleep identified during the assumed sleep period.
5. Immobile minutes - reflects the number of minutes within the assumed sleep period that were scored as immobile (i.e., without detectible movement).
6. Fragmentation index - reflects the amount of movement or disrupted sleep.

3.3 Procedure

Following informed consent, volunteers were assigned a subject number. Subsequently, the PI and research staff issued an Actiwatch® to each participant. Each Actiwatch® was identifiable by serial number and matched to the subject number. The donning of each Actiwatch® on the subject's wrist was supervised by the research staff to ensure proper placement. The volunteer was instructed that the Actiwatch® had to remain on the arm for the duration of the study unless removed for unforeseen health, discomfort, and/or safety reasons.

Activity data (the predictor variable) was recorded automatically by the Actiwatch® throughout the duration of the predetermined course-specific period. At course completion, the Actiwatches® were retrieved and the data downloaded. Due to the variability of training syllabi, the exact number of days varied.

Although the duration of the study differed according to the specific military occupational skill (MOS) of the volunteer, all groups engaged in a similar process. 1) All participants donned the actigraph and wore it continuously for the duration of the study; 2) each participant completed at least three classroom examinations during the course of the study; and 3) at the completion of the study, each subject returned their actigraph and the data was downloaded to a computer database.

All performance evaluations were conducted by the military course cadre with performance scores passed to the research team upon course completion. Military relevant performance measures (the outcome variables) were those measures/exam scores applicable to the particular course of instruction. Performance measures and the specific times and dates of their collection were amassed for performance-activity comparisons. All identifiable data (name/serial numbers) were converted to subject number reference to ensure subject confidentiality.

3.4 Data preparation and analysis

3.4.1 Data retrieval

Retrieval attempts of the 106 Actiwatches® found that three devices were lost during the data collection period leaving 103 available for downloading. Each Actiwatch® was downloaded using the Actiwatch® Reader. Due to unexplained technical difficulties, data were only recorded on 79 Actiwatches®. For each participant, an individual data file (i.e., .AWD file) was downloaded and saved. This file included a header with the individualized subject number, date and time of actigraph initialization, and basic demographics of the participant, and a column of data points representing minute-by-minute activity counts for the duration of the study.

3.4.2 Data cleaning

Initial data cleaning included the exclusion of data from three participants who admitted to removing the devices during the collection period. For unknown reasons, 21 Actiwatches® failed to download any activity data. Of the remaining 79 Actiwatches®, 32 collected data for less than 20 days. Participants with obviously missing data were excluded from the data set.

As a second stage of data cleaning, a sample of data files was opened in the Actiware® actigraphy analysis program version 3.41 and inspected for quality by a trained and experienced sleep scientist. This visual inspection was used to identify records that were clearly atypical (e.g., zero activity for many continuous hours), and remove those from the dataset. This was followed by a final cleaning of the data by computer algorithm details of which are available in Killgore et al. (in press). The data from a total of 64 Actiwatches® were used in this analysis.

3.4.3 Overall data analysis

Two approaches were undertaken to analyze the present data: Approach 1) Use only Actiwatch® sleep scores from the two days preceding the exam to predict performance on the exam; and Approach 2) Use only Actiwatch® sleep scores from one day preceding the exam to predict exam performance.

4. RESULTS

4.1 Statistical analyses

All statistical analyses were conducted using SPSS[x] 12.0 with statistical significance set at an alpha level of .05 for all statistical exams.

4.2 Actiware analyses

4.2.1 Average total sleep per night

From the valid Actiware scores, the average sleep per night was calculated for the sample as a whole ($n = 64$). The mean sleep obtained per night across all classes evaluated was 5.80 hr ($SD = 0.55$). Figure 1 shows the distribution of average nightly sleep for the entire sample, which ranged from a minimum of 4.5 hr to a maximum of 7.5 hr per night. The National Sleep Foundation recommends that adults obtain 7 to 9 hr of sleep per night. In the present sample, only three Soldiers (3.1 percent) met this criterion for adequate sleep.
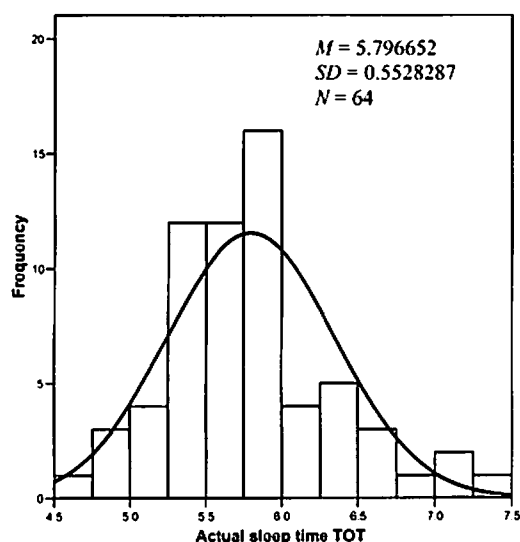
$M = 5.796652$
$SD = 0.5528287$
$N = 64$

Figure 1. Histogram of the mean hours of sleep obtained by all participants for the entire duration of the study.

4.2.2 Total sleep time

It was also of interest to examine whether there were significant differences among the various courses in the average amount of sleep obtained by the class members. A one-way analysis of variance (ANOVA) showed that there was, in fact, a significant main effect of course on the amount of sleep obtained, $F(5,58) = 3.09$, $p = .015$.

Table 1.
Group statistics for total sleep time in hours.
(* Significant [$p < .05$] pair-wise differences with Maintenance NCO course. † Significant [$p < .05$] pair-wise differences with 15Q40 course.)

Course	M	SD	SE	95%CI Lower	95% CI Upper	Min	Max
Maintenance (n=13)	6.17	.45	.12	5.89	6.44	5.59	7.03
15P30 (n=8)	5.67*	.49	.17	5.26	6.087	4.92	6.45
15Q30 (n=10)	5.86	.80	.25	5.28	6.43	4.93	7.46
15Q40 (n=6)	6.09	.52	.21	5.53	6.64	5.37	6.73
WOC 17 (n=20)	6.17* †	.45	.12	5.89	6.44	5.59	5.98
WOC 18 (n=7)	5.67* †	.49	.17	5.26	6.08	4.92	6.50

Post-hoc pair-wise comparisons (LSD exams) showed that the Maintenance Course and the 15Q40 Course generally obtained the most sleep whereas the 15P30 and both WOC obtained the least. Significant (*p* < .05) pair-wise differences were discovered between the Maintenance NCO course and the 15P30, WOC 17, and

WOC 18 courses. Complete data for total sleep time in all groups can be found in table 1.

4.2.3 Prediction of exam performance from actigraphy

4.2.3.1 Overview

A goal of this study was to evaluate the effectiveness of actigraphy as a predictor of cognitive performance. For the present study, the dependent variable was performance on the first examination in each course. This examination differed across courses and did not necessarily contain the same content. However, examination scores were converted to percent correct for analysis, so that they were all on a similar scale. Due to small samples within each class, the subjects from all different classes and courses were combined into a single sample, despite differences in course content. By combining scores across courses, it was possible to obtain a conservative and broadly generalizable examination of the effects of sleep on cognitive performance (i.e., the procedure tested the effects of sleep/wake schedules on "exam performance" broadly defined, rather than on a specific course content). Several indices of sleep quality were used to predict performance on these examinations across all participants in the study. In order to ensure that valid data were obtained for prediction, we only selected cases that had at least five days of valid data prior to the examination.

4.2.3.2 Total sleep prior to exam 1

It was of interest to examine the amount of sleep obtained during the period encompassing the two-day period prior to exam 1 as well as one-day prior to exam 1. By comparing these indices to overall sleep during the course, it was possible to evaluate whether subjects obtained less sleep in the day or two prior to taking an exam (e.g., staying up late "cramming" for the exam). For this analysis, 38 participants had valid data for the five days prior to exam 1. From the Actiware analyses it was determined that the mean hours of sleep obtained over the two-day period prior to the first exam was 4.83 ($SD = 0.74$). A paired-samples t-test revealed that this amount of sleep over that two-day period was significantly lower than the average sleep obtained by this subsample ($M = 5.79$, $SD = 0.47$) over the duration of the entire study, $t(37) = 9.69$, $p < .001$, suggesting that subjects were altering their normal sleep in the two-day period prior to the exam. Similarly, when the analysis was restricted to one day prior to the first exam, participants obtained a mean of 4.62 hr ($SD = 1.15$) of sleep, which was significantly less than they obtained two nights before the exam, $t(37) = 2.07$, $p = .046$. This

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suggests that normal sleep patterns were significantly reduced the night before an exam.

4.2.3.3 Relationship between total sleep and performance

Given that some Soldiers altered their normal sleep prior to the exam period, it was of interest to predict their performance on the exam based on the amount of sleep obtained in the preceding nights. Actigraphically measured sleep was entered into a correlation analysis with performance on exam 1. The average sleep obtained during the two days preceding the exam was significantly and positively correlated with exam performance ($r = .60, p < .001$), despite the fact that the exams were from different courses and covered different content. Similarly, when only sleep from the one day preceding the exam was evaluated, there was still a highly significant positive correlation between the amount of sleep obtained and exam scores ($r = .54, p < .001$). These findings suggest that those Soldiers who obtained the most sleep during the two nights preceding the exam performed significantly better than Soldiers who obtained less sleep.

4.2.3.4 Relationship between sleep latency and performance

Sleep latency reflects the amount of time required to fall asleep once it was determined that an individual Soldier was probably in bed and attempting sleep. For every Soldier, this index was calculated according to the standard algorithm provided by the Actiware program for each night of sleep. Sleep latency scores were entered into a correlation analysis with performance on exam 1. The average sleep latency during the two days preceding exam 1 was significantly and negatively correlated with exam performance ($r = -.46, p = .002$). Nearly identical results were obtained when only sleep from the one day preceding the exam was evaluated, with a highly significant negative correlation between sleep latency and exam scores ($r = -46, p = .002$). These results suggest that Soldiers who had the greatest difficulty falling asleep during the two nights preceding the exam tended to also have the lowest scores on that exam.

4.2.3.5 Relationships between other actigraphic indices and performance

The Actiware program provides indices on a number of potentially important sleep variables. The relationships between these variables and exam 1 performances are briefly summarized below:

The assumed sleep variable was determined by the Actiware scoring algorithm and reflects the amount of time between the point at which it appears that the onset of the sleep period began and the time that the participant finally arose from sleep. This variable only counts the elapsed time from assumed sleep onset to the end of the sleep period, but does not account for brief periods of waking or sleep between those two points. This index, while only a crude estimate of sleep time, was positively correlated with exam 1 scores for the two day and one day periods preceding the exam (two-day $r = .51, p = .001$; one-day $r = .48, p = .001$).

The actual wake time variable was determined by the Actiware scoring algorithm and reflects the number of minutes of time within the assumed sleep period that were spent awake (i.e., not scored as sleep). This variable was not significantly correlated with exam performance for either the two day ($r = .20, p = .12$) or one day ($r = .21, p = .11$) periods preceding the exam.

The sleep efficiency variable was determined by the Actiware scoring algorithm and indicated the percent of time that a Soldier was assumed to be "in bed" or attempting to sleep that was actually spent asleep. Strong positive correlations were found with exam scores when this variable was averaged over the two days prior to the exam ($r = .60, p = .001$) as well as when evaluated only for the night preceding the exam ($r = .54, p = .001$).

The number of sleep bouts variable was determined by the Actiware scoring algorithm and reflected the number of independent bouts of sleep identified during the assumed sleep period. The number of bouts of sleep was positively correlated with exam 1 performance for the two-day ($r = .53, p < .001$) and one-day ($r = .56, p < .001$) measurement periods.

The immobile minutes variable was determined by the Actiware scoring algorithm and reflected the number of minutes within the assumed sleep period that were scored as immobile (i.e., without detectible movement). The number of minutes scored as immobile was positively correlated with exam performance when evaluated over the two days prior to the exam ($r = .58, p < .001$) as well as when evaluated for just the one day before the exam ($r = .52, p = .001$).

The fragmentation index was determined by the Actiware scoring algorithm and reflected the amount of movement or disrupted sleep. Interestingly, this variable was also positively correlated with performance on exam 1. Greater fragmentation of sleep during the two days prior to the exam was modestly associated with better exam performance ($r = .29, p = .04$). This pattern was also evident when assessed only for the one day prior to the exam ($r = .28, p = .05$).

5. DISCUSSION

The primary objective of this study was to obtain actigraphic measurements of sleep in a sample of Soldiers during military education/training and to use those data to examine the relationship between sleep and militarily relevant performance. The present study yielded several important outcomes:

1. Actigraphic measurement of sleep can be obtained successfully and unobtrusively within a militarily relevant environment.
2. Actigraphic data can be reliably organized and scored using automated algorithms to identify poor quality data.
3. Semi-automated Actiware sleep scoring suggested that many Soldiers obtained sub-optimal amounts of sleep per night during military education and the amount of measured sleep obtained by these Soldiers was directly and significantly related to military course performance.

Together, these findings provide preliminary support for the use of actigraphy to measure sleep/rest in militarily relevant settings. These results also demonstrate the importance of adequate sleep for course learning and retrieval.

While actigraphy has been used successfully for several decades within laboratory and some field settings, there have often been difficulties with subject compliance and the ability to obtain reliable and valid measurements. As the ultimate goal is to use actigraphy in actual combat operations to aid in sustaining the health of the force and to optimize command decisions regarding manpower allocation, it is critical to demonstrate that actigraphy can be obtained reliably and unobtrusively with Soldiers in militarily relevant settings. The present data provide a mixed picture regarding the ability to obtain useful data in a military setting. Following extensive data cleaning and validity checks, 59% of the sample had reliable and valid data that were complete enough for inclusion in the final statistical analyses. Of those data that were obtained, the results and predictive validity were impressive. The correlations between the amount of obtained sleep and subsequent course performance were highly significant. Unfortunately, the present study suffered from a high level of data loss. Twenty-three percent of the returned Actiwatches failed to record any activity data. From the post-collection analysis, it was not clear whether this loss of data was due to a mechanical malfunction, battery failure, or human error in initializing the actigraphs at the start of the study. Although the data collected were highly predictive and meaningful, future studies must address the unacceptably high failure rate of the actigraph recording devices such as that experienced in this study..

One of the major difficulties in using actigraphy in a combat or other field environment is the extent of pre-processing and data management necessary to transform the large data streams into a form that is readily usable for describing current sleep levels and making performance predictions. The present study attempted to outline the elementary steps necessary to take raw activity counts from the Actiwatch and transform them into a form that could be analyzed in standard statistical packages, spreadsheets, or entry into stastical models. Simple data quality assessment tools were created and automated in Microsoft Excel to evaluate the validity of the obtained data. This process was accomplished via simple macros written in Microsoft Excel and which could potentially be implemented into self-contained free-standing software programs. These processes were then compared to manual scoring/assessment procedures and were found to produce agreement exceeding 98% between the manual and automated validation procedures. These findings suggest that it may be possible to automate many of the pre-processing and validation stages to make actigraphic analysis of sleep data feasible and expedient in field environments.

In order for the actigraphic measurement of sleep to be useful in military settings, it must be shown to be meaningfully related to relevant indices of performance. The present results showed that Soldiers undergoing military training courses obtained an average of 5.8 hr of actigraphically measured sleep per night, an amount that is significantly less than the 7 to 9 hr generally recommended as healthy for adults (http://www.sleepfoundation.org). In fact, for the sample as a whole, greater than 95% of the participating Soldiers obtained less than the minimum recommended 7 hr of sleep per night on average throughout the duration of the course. This suggests that the sleep habits of Soldiers while attending these courses is generally below what is considered adequate for long term health of normal adults. Poor sleep is related to a variety of health problems and chronic illnesses. The potential consequences of prolonged inadequate sleep in terms of physical health, well-being, and readiness of the force are issues that should be considered in the design and implementation of future military training programs.

It was also of interest to determine whether the amount of obtained sleep during military training was meaningfully related to course performance. Accordingly, outcome data were collected in the form of exam scores from the various courses. Due to small class sizes and availability of specific Soldier samples, the groups comprised several different military courses, including the WOC School and several different tracks

of the NCO Academies. The outcome measures included performance on the first exam and performance on all course exams. It is important to note that these exams differed in content across the various courses. Despite the variability in exam content, overall percent correct on pooled exam scores across all courses was significantly predicted by several sleep related variables. In some cases, the average amount of sleep obtained by Soldiers accounted for approximately 40% of the variance in exam scores. This finding underscores the importance of adequate sleep on cognitive functioning, including learning and retention of military relevant information. Soldiers that obtained more sleep were generally more able to benefit from training, retained more information, and obtained higher exam scores than their peers that obtained less sleep. Also, the amount of sleep obtained was related to the variability or "instability" of exam scores. Close examination shows that those Soldiers that consistently averaged the highest amounts of sleep obtained consistently high exam scores, whereas those that averaged low levels of sleep obtained inconsistent performances on the exams, with some doing quite well and others receiving failing or only marginally passing grades. Thus, one of the most important factors associated with performing well in these military courses was the degree to which a Soldier obtained adequate sleep on a consistent basis.

6. LIMITATIONS

The present study suffers from certain weaknesses. First, the significant loss of data was problematic and suggests that the use of actigraphy in non-laboratory studies is still prone to considerable mechanical and/or human error. Future studies need to be vigilant about minimizing these problems either through automation or more effective staff training. Second, the loss of data limits the generalizability and power of the study. Future studies with larger samples are necessary to establish the reliability of these findings. Third, the outcome variable in the present study was "exam score" without regard for the specific content of the course, the teaching methods used, or other variables that may have impacted the data. On one hand, the fact that actigraphic sleep predicted performance on such a loosely defined outcome variable as exams to the robustness of sleep as a factor in cognitive performance, the study would have been more precise had the dependent variable been the same across all subjects. Furthermore, the present findings are only applicable to the types of course content presented in the WOC School and NCO Academies. These dependent variables represent general learning and retention of textbook military content. While the present findings suggest that performance on this type of material in an academic environment is adversely affected by inadequate sleep, it remains unclear whether actigraphic

measurement of sleep is related to other types of cognitive performance in the field. These are issues to be examined in subsequent research.

7. CONCLUSIONS

This study was conducted to determine if performance models based on sleep history and activity levels could predict academic exam performance in the NCO Academy and Warrant Officer Candidate School at Fort Rucker, AL. Analysis of the sleep and activity data from six classes showed that, independent of the Soldiers' academic background, type of school, or exam content, the amount of sleep during the two nights prior to an academic exam accounted for up to 40% of the variance in exam scores. Prior activity levels were not predictive. These data support the use of actigraphy for forecasting cognitive performance in military personnel. These data suggest that actigraphy can be easily and unobtrusively collected from military personnel and provide useful real-time information about the readiness of Soldiers and aircrew. Such easily obtained data may improve military decision-making as well as potentially save lives and equipment.

DISCLAIMER

The opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the U.S. Army and/or the Department of Defense.

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